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HIGH GAIN, STEERABLE MULTIPLE BEAM ANTENNA SYSTEM

CLAIMING BENEFIT OF PRIOR FILED PROVISIONAL APPLICATION

This application claims the benefit of U.S. Provisional Application Serial No. __________ filed on September 27, 2002 and entitled "High Gain, Steerable, Multiple Beam Antenna System" which is incorporated by reference herein.

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to the communications field, and in particular, a high-gain, multi-beam, 360 degree antenna system.

BRIEF DESCRIPTION OF THE INVENTION

The present invention is a multi-beam antenna system that can be used in microwave frequency applications between 1 GHz and 100 GHz. The multi-beam antenna system

covers four 90° sectors for full 360° coverage. Each 90° sector is covered with at least 1 narrow steerable transmit (TX) and 1 narrow steerable receive (RX) beam. The beams are steered in the azimuth dimension.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete understanding of the present invention may be had by reference to the following detailed description when taken in conjunction with the accompanying drawings wherein:

FIGURE 1 is a plan view diagram that illustrates a multi-beam antenna system in accordance with the present invention;

FIGURE 2 is a diagram illustrating in greater detail one way a controller can be used to control the multi-beam antenna system shown in FIGURE 1;

FIGURE 3 is a diagram illustrating in greater detail the components of a single aperture that can be used within the multi-beam antenna system shown in FIGURE 1;

FIGURE 4 is a diagram illustrating in greater detail the components of a beam former that can be used within the multi-beam antenna system shown in FIGURE 1;

FIGURE 5 is a diagram illustrating in greater detail the components of a secondary power combiner/splitter and the radiating elements that can be used within the multi-beam antenna system shown in FIGURE 1;

FIGURES 6A and 6B are diagrams that illustrate different feed structures that can be used in the primary

power combiner/splitter shown in FIGURE 4 and the secondary power combiners/splitters shown in FIGURE 5;

FIGURE 7 is a diagram that illustrates how the beam former shown in FIGURE 4 can be connected to the centre-series feed secondary power combiner/splitter shown in FIGURES 5 and 6B;

FIGURE 8 is a diagram that illustrates one way to package the multi-beam antenna system shown in FIGURE 1;

FIGURES 9A and 9B are diagrams of another embodiment of the multi-beam antenna system shown in FIGURE 1;

FIGURE 10 is a diagram of one of the four radiation element array panels used in the multi-beam antenna system shown in FIGURES 9A and 9B; and

FIGURE 11 is a diagram of a controller implemented within the multi-beam antenna system shown in FIGURES 9A and 9B.

DETAILED DESCRIPTION OF THE DRAWINGS

The multi-beam antenna system 100 includes four pairs of independent TX (transmit) and RX (receive) apertures 110 that are arranged into a square formation as shown in FIGURE 1 (see also FIGURE 8). Each pair of TX and RX apertures 110 emits a pair of TX and RX radiation beams 112 that cover one 90° wide sector, so that the multi-beam antenna system 100 can cover the full 360° range.

The multi-beam antenna system 100 also includes a controller 115 (e.g., embedded controller 115) shown in FIGURE 2 that performs all of the tasks related to pointing

the radiation beams 112. The controller 115 performs the following functions:

- Receive and execute antenna commands 202
- Control the RF switches 204.
- Adjust the tunable phase shifters 206

In particular, the controller 115 receives the antenna commands 202 from a radio's media access controller (MAC) 208 and executes the commands 202 in order to point any of the eight radiation beams 112 to a specific azimuth setting. The radiation beam 112 pointing functions are carried out through the use of electronic RF switches 204 and phase shifters 206. The RF switches 204 are used to select a particular aperture 110 or antenna quadrant while the phase shifters 206 on each of the four sides of the multi-beam antenna system 100 are adjusted to achieve incremental steering of the radiation beams 112. Alternatively, the multi-beam antenna system 100 can be fed by four separate transceiver systems, allowing for four simultaneous RX beams 112 and four simultaneous TX beams 112.

Each TX and RX aperture 100 as shown in FIGURE 3 includes multiple rows and columns of radiating elements 302. The radiating elements 302 in each column are connected together via microwave transmission lines in a column secondary power splitter 304 (in the RX aperture 100) or column secondary power combiner 304 (in the TX

aperture 100). The secondary power splitter/combiners 304 are connected to a beam former 306 that steers the radiation beam 112 in one dimension which in the preferred embodiment is the azimuth direction. Above 10 GHz, the transmission lines and/or secondary power combiners/splitters 304 are usually realized in waveguides to minimize loss, but microstrip or stripline transmission lines and power combiner/splitters can be used up to about 30GHz. Waveguide transmission lines and power combiners/splitters can also be used below 10GHz, but the structure can become quite bulky. Co-axial transmission lines are also practical below about 3GHz. With the use of microstrip, striplines or co-axial lines, wide bandwidth corporate feed structures are easily realizable, such a structure is shown in FIGURE 6A. Waveguide corporate feed structures are very bulky, requiring significant amounts of volume. For this reason, series fed waveguide structures are used instead when the operating bandwidth is narrow (less than 5% of the operating frequency), as shown in FIGURE 6B. The series fed waveguide structure is used in the preferred embodiment of the primary power combiner/splitter 308 (see FIGURE 4) and the secondary power combiners/splitters 304 (see FIGURE 5).

As shown in FIGURE 4, the beam former 306 includes a primary power combiner/splitter 308 (e.g., centre fed waveguide 308) which distributes/collects power in a serial manner to/from the row of phase shifters 206. The phase shifters 206 in turn fed the column secondary power

combiners/splitters 304 having the form of secondary waveguides at their respective centres, which finally distribute power again in a serial fashion to the radiating elements 302 (e.g., antenna elements 302)(see FIGURE 3). This waveguide feed arrangement is in particular the most practical for Ku-band and Ka band applications since it is compact. In addition, this waveguide feed arrangement ensures low loss power transmission.

The beam former 306 as depicted in FIGURE 4 has a co-axial cable 310 feeding the primary power combiner/splitter 308 (e.g., primary waveguide 308) at its centre. The primary waveguide 308 is coupled to a row of phase shifters 206 via broad wall slots 312 that are spaced roughly at half guided-wavelengths along the length of the primary waveguide 308. The spacing is not important, since the phase shifters 206 can be used to correct any phase differences, therefore it can be adjusted to match the widths of the secondary waveguides 304 (e.g., secondary power combiners/splitters 304)(see FIGURE 7). The phase shifters 206 shown here are slotline phase shifters 206 where the slot gaps are loaded with a voltage tunable ferroelectric material. In the preferred embodiment, the voltage tunable ferroelectric material is made and sold under the name of Parascan™ material by Paratek Microwave, Inc. A bias voltage applied across the slotline gap is used to control the dielectric constant of the voltage tunable material, and hence the velocity of propagation in the slotline. The phase shifters 206 are designed with

enough length to vary at least one wavelength in electrical length over the possible bias voltage range, thereby creating 360° of phase shift. The slotline gap width can be varied along its length, to create a non-uniform loaded slotline. This technique which is done to allow a low biasing voltage to be used without increasing metallic current losses is described in greater detail in U.S. Patent Application Serial No. 10/199,724 entitled "A Tunable Electromagnetic Transmission Structure for Effecting Coupling of Electromagnetic Signals" that was filed August 19, 2002. The contents of this patent application are hereby incorporated by reference herein.

Each phase shifter 206 in the beam former 306 couples to the centre of a secondary waveguide 304 (e.g., secondary power combiner/splitter 304) as shown in FIGURE 5. The secondary waveguide 304 couples to a column of the antenna elements 302 via broad wall slots 314 along its length. The slots 314 are spaced at half a guided wavelength apart, alternating on different sides of the waveguide's centre line. This ensures that the slots 314 are excited in series and in phase, since the broad wall current distribution flows away from the centre line of the secondary waveguide 304. The antenna elements 302 shown are stacked rectangular patches. These can be of any other shape (elliptical, polygon) as long as the radiated field exhibits polarization purity and power can be transmitted/received into/from space efficiently. Other types of antenna elements 302 can be used such as Vivaldi

elements. Alternatively, the slots 314 themselves can be used as radiating elements 302. FIGURE 7 is another diagram that illustrates how the beam former 306 can be connected to multiple centre-series feed secondary power combiners/splitters 304.

Referring to FIGURE 8, there is a diagram that illustrates one way to package the multi-beam antenna system 100 shown in FIGURE 1. The multi-beam antenna system 100 scans 1-D beam(s) 112 (narrow in azimuth with scanning and narrow in elevation with fixed cosecant squared null fill) anywhere within 360 degrees. The package shown is a truncated pyramid where each face or aperture 110 contains individual transmit and receive arrays. All of the components both RF elements (dividers, combiners, switches, phase shifters, amplifiers...) and control elements (power supply...) are contained within the package.

One embodiment of the multi-beam antenna system 100 may have the following requirements shown in TABLE #1:

TABLE #1

	Transmit	Receive
Frequency	14.7-14.9 GHz	15.1-15.3 GHz
Polarization	RHCP	LHCP
Beam Steering	360 degree Azimuth (fixed beam in Elevation) each single panel providing +/- 45 degree azimuth scan	

Beamwidth Azimuth half-power	5 degree Az	
Beamwidth Elevation half-power	5 degree El--shaped with cosecant squared null fill in the up direction	
Beam scan/switching time	< 10 ms (based on 20 mrad/sec tracking requirement)	
Maximum incoming power	20W	20W
Antenna gain	24 dBi	24 dBi
Antenna EIRP	37 dBW per beam	-
Front-to-Back ration (F/B)	>20dB	>20dB
Return Loss	<-14dB (1.5:1 VSWR)	<-14dB (1.5:1 VSWR)
Impedance	50Ω	50Ω
Polarity discrimination	> 20dB	
Antenna Size	~36"x36" footprint by ~16" high	

Referring to FIGURES 9-11, there are several diagrams illustrating another embodiment of the multi-beam antenna system shown in FIGURE 1.

Following are some of the different advantages and features of the multi-beam antenna system 100 of the present invention:

- The phase shifters 206 in the preferred embodiment incorporates a voltage tunable ferroelectric material comprised of Barium-

Strontium Titanate, $Ba_xSr_{1-x}TiO_3$ (BSTO), where x can range from zero to one, or BSTO-composite ceramics. Examples of such BSTO composites include, but are not limited to: BSTO--MgO, BSTO--$MgAl_2O_4$, BSTO--$CaTiO_3$, BSTO--$MgTiO_3$, BSTO--$MgSrZrTiO_6$, and combinations thereof. Following is a list of some of the patents which discuss different aspects and capabilities of the voltage tunable ferroelectric material all of which are incorporated herein by reference: U.S. Patent Nos. 5,312,790; 5,427,988; 5,486,491; 5,635,434; 5,830,591; 5,846,893; 5,766,697; 5,693,429 and 5,635,433.

- The phase shifters 206 can be configured as anyone of the phase shifters disclosed in U.S. Patent Nos. 6,377,217; 6,621,377; 6,538,603; and 6,590,468. Or disclosed in U.S. Patent Application Serial Nos. 09/644,019 (August 22, 2000); 09/838,483 (April 19, 2001); 10/097,319 (March 14, 2002); 09/931,503 (August 16, 2001); and 10/226,746 (August 27, 2002). The contents of these patents and patent applications are hereby incorporated by reference herein.

- The multi-beam antenna system 100 can revolutionize communications for ground or aerial based command and control assets.

- The multi-beam antenna system 100 enhances the spatial and frequency agility of communication networks--at the antenna and the receiver system.

- The multi-beam antenna system 100 can be used in mobile ad-hoc networks.

While the present invention has been described in terms of its preferred embodiments, it will be apparent to those skilled in the art that various changes can be made to the disclosed embodiments without departing from the scope of the invention as set forth in the following claims.